

LWIR Confinement-enhanced Dots-in-a-well QDIPs with Operating Temperature over 200K

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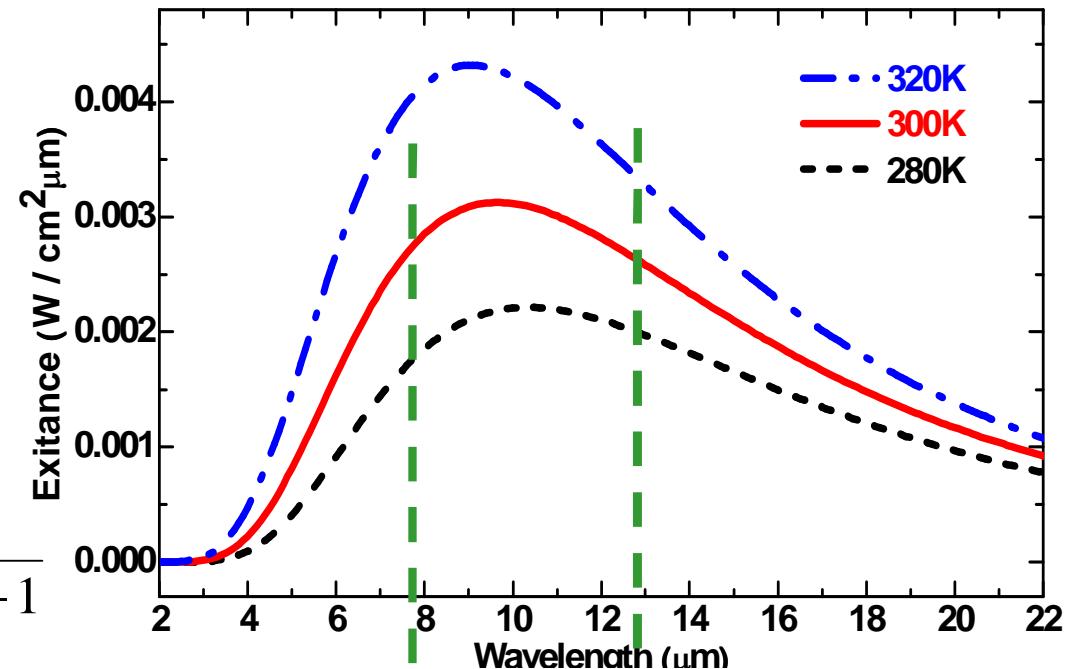
The technology of LWIR photodetectors is important but relatively challenged especially for high temperature operations. In this talk, we propose a **confinement-enhanced DWELL** structure to the realization of high performance **LWIR QDIPs**.



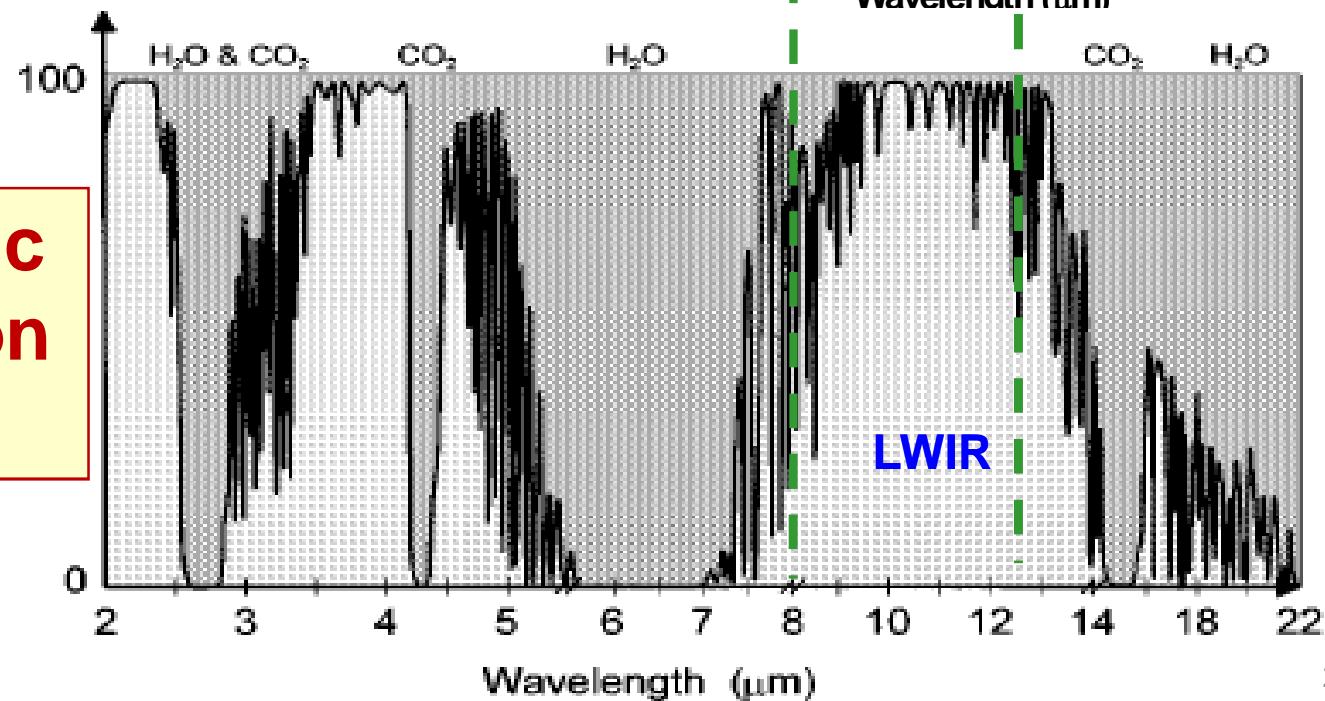
Why we need LWIR detectors?

Blackbody radiation

$$M(T, \lambda) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$



Atmospheric transmission spectrum

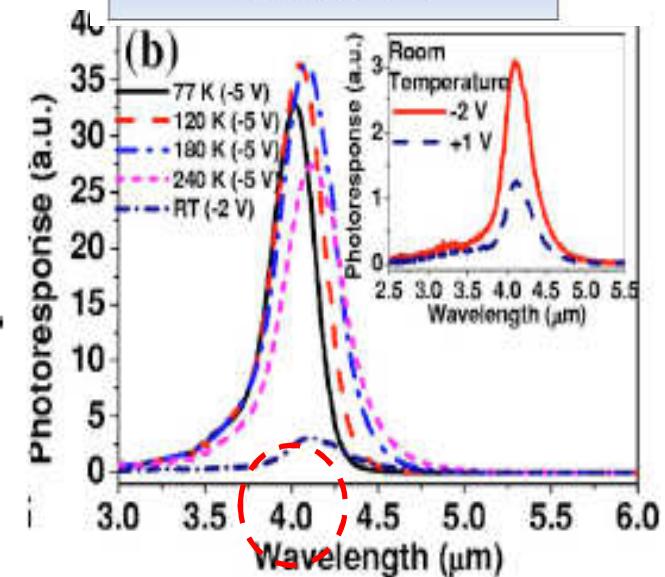
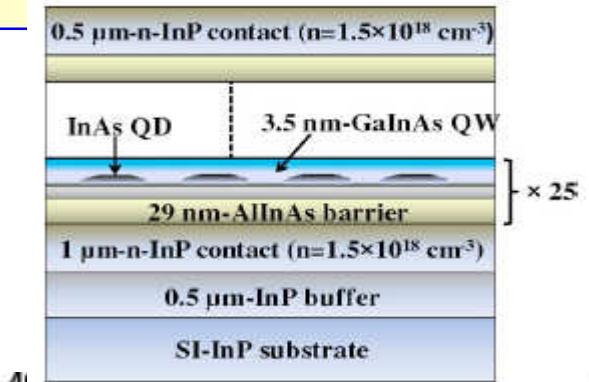
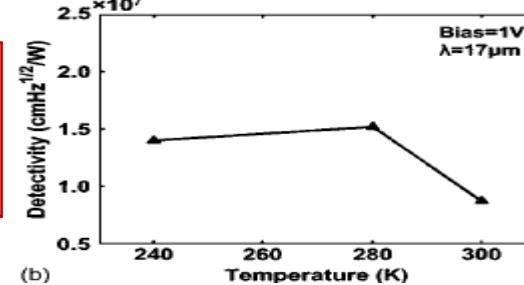
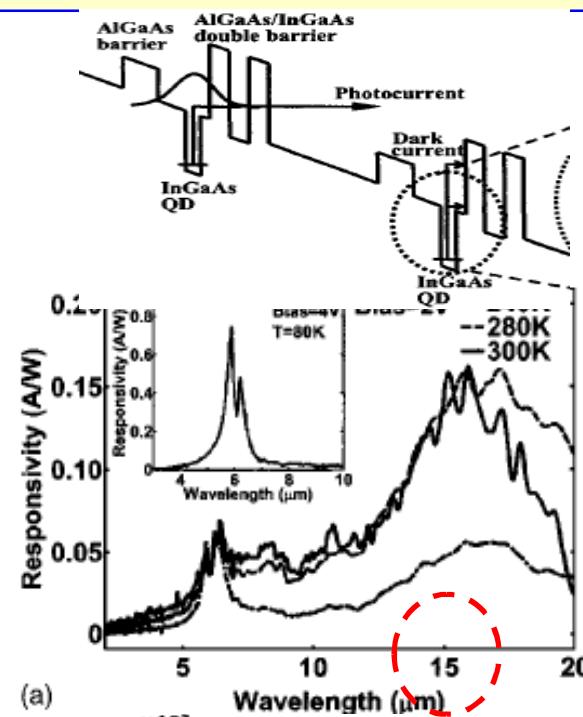
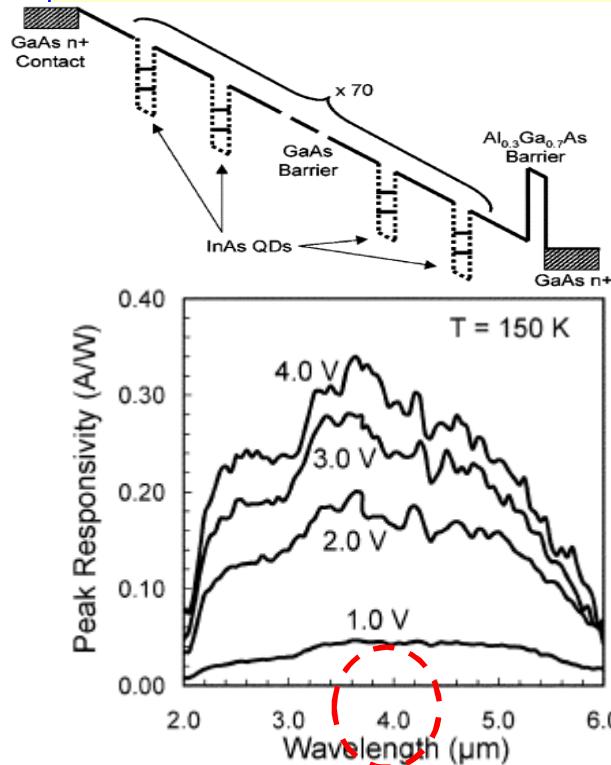


- With the 3D carrier confinement of QDs, QDIPs with High operating temperatures has been demonstrated.

---- S. Chakrabarti et al. IEEE Photon. Tech. Lett. 16 (2004)

---- P. Bhattacharya et al. Appl. Phys. Lett. 86 (2005)

---- H. Lim et al. Appl. Phys. Lett. 90 (2007)



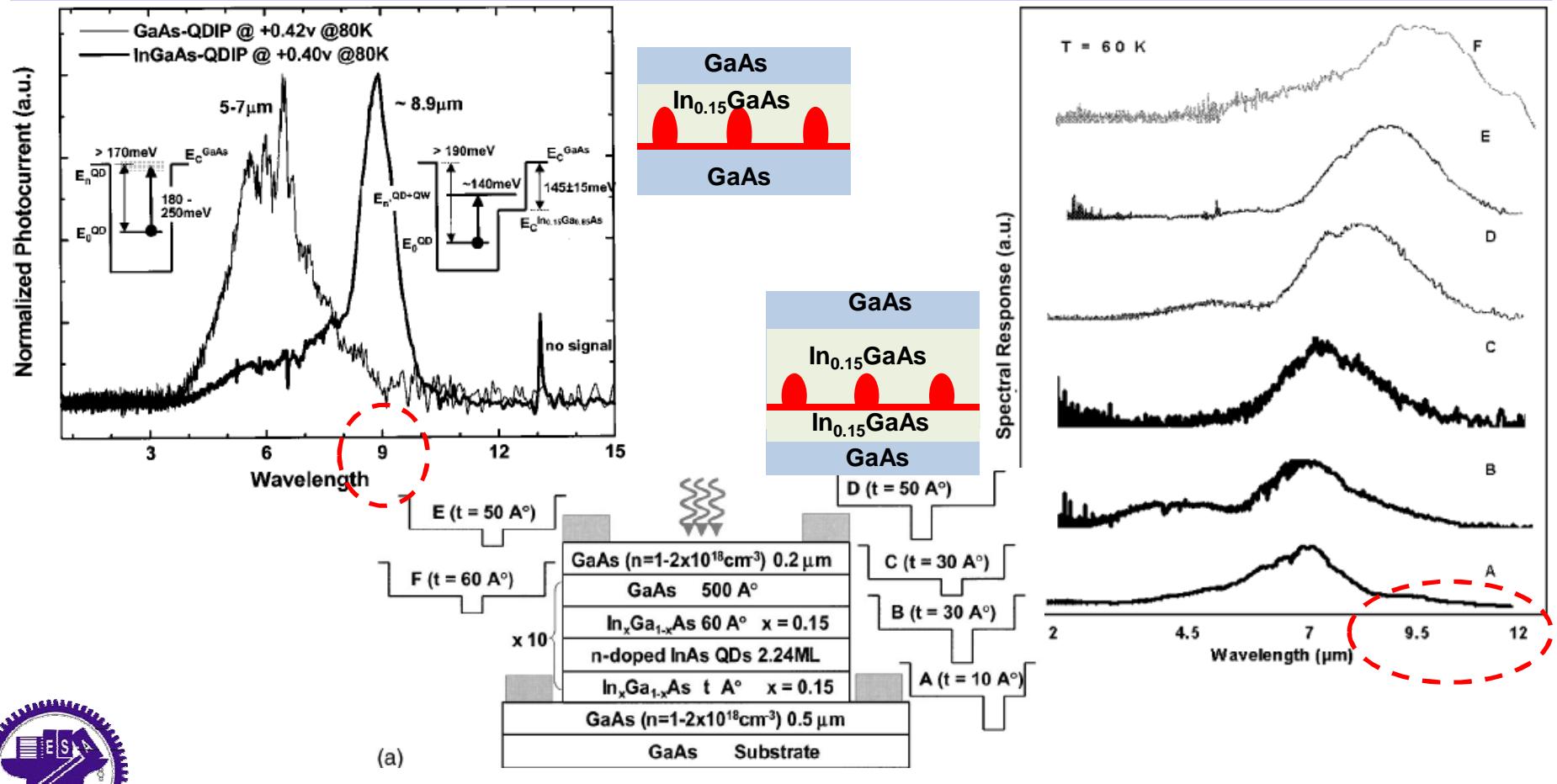
**MWIR &
VLWIR**

LWIR QDIPs

- Wavelength tuning provided by DWELL QDIPs.

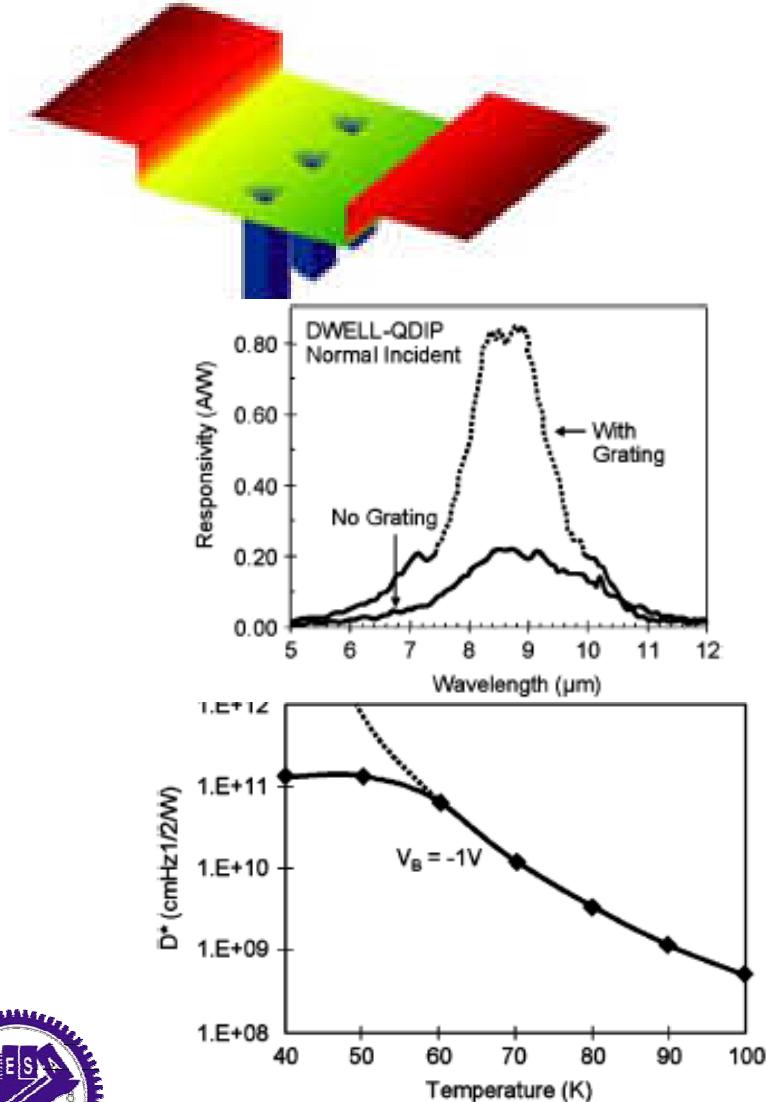
---- Eui-Tae Kim et al. Appl. Phys. Lett. 79 (2001)

---- S. Raghavan et al. J. Appl. Phys. 96 (2004)

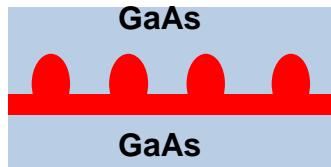


● 640 x512 LWIR DWELL QDIP Imaging Focal Plane Array.

---- Sarath D. Gunapala et al. IEEE J. Quantum Elect. 43 (2007)

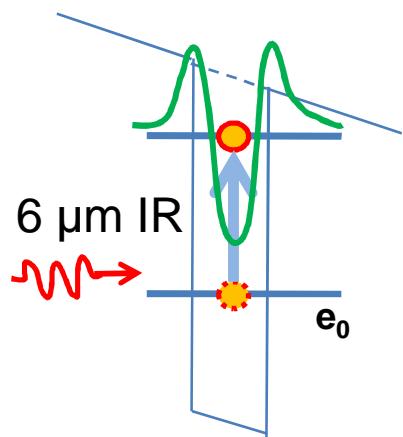


The advantages & disadvantages of conventional DWELL QDIPs

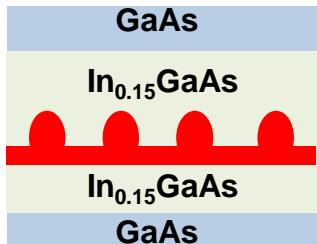


InAs/GaAs QDs

Ψ_{ex} : localized

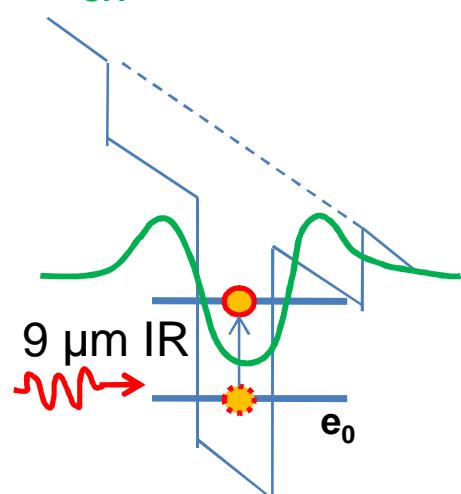


State energy:
shallower



InAs/InGaAs/GaAs
DWELL

Ψ_{ex} : extended



State energies: deeper

● LWIR detection band (good!)

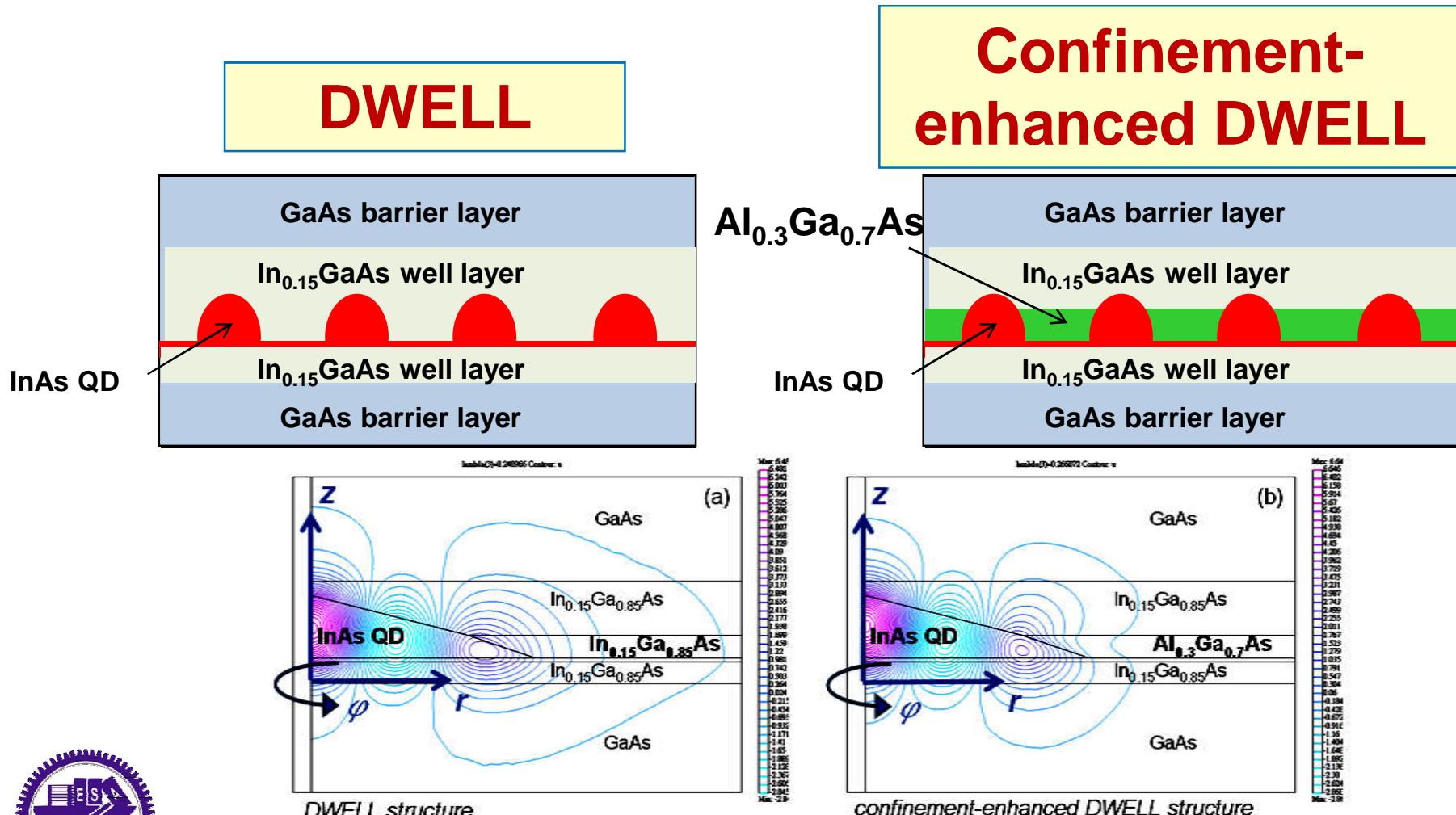
● Lower dark current (good!)

● Smaller oscillation strength & smaller escape probability

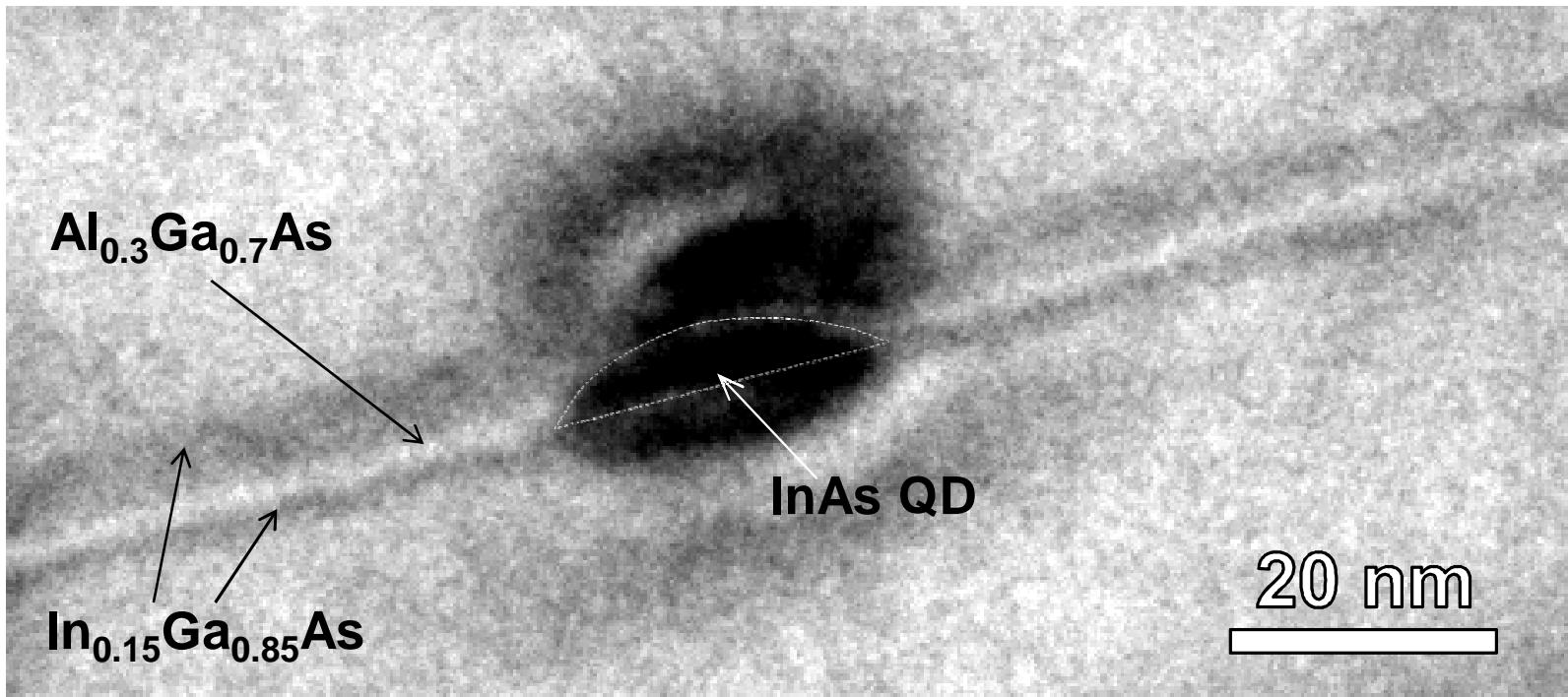
=> lower QE (bad!)



A method to enhance the QE : insertion of a thin AlGaAs layer on the QDs in the DWELL to enhance the quantum confinement effects.

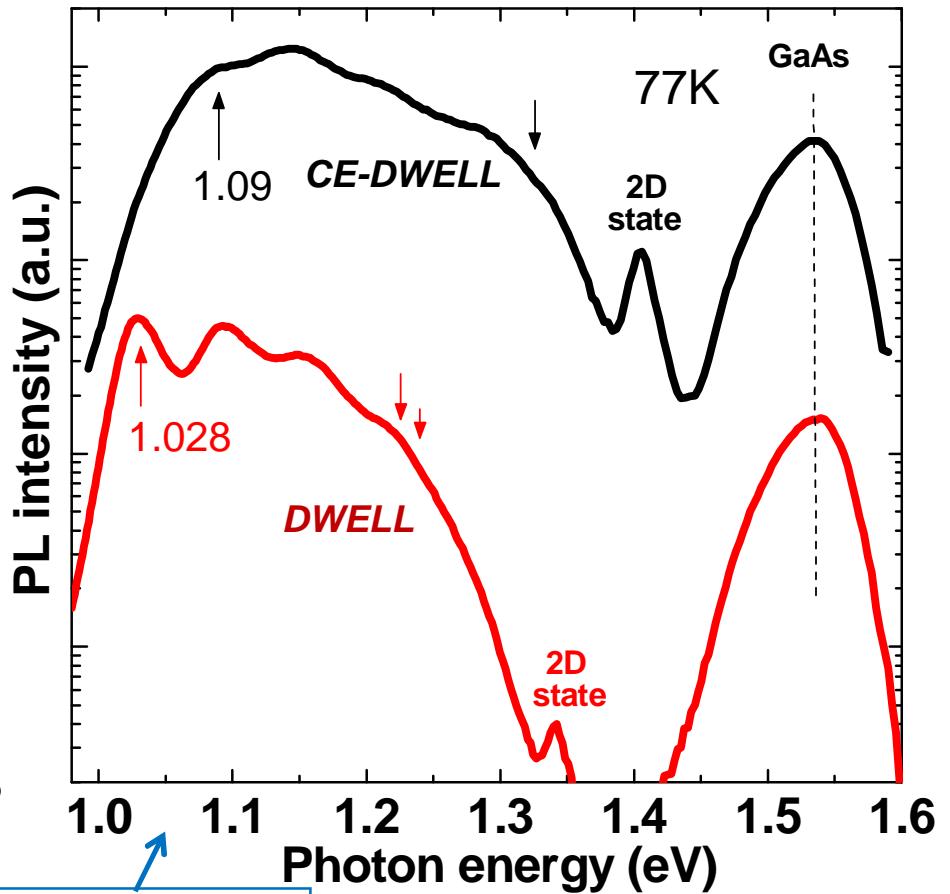
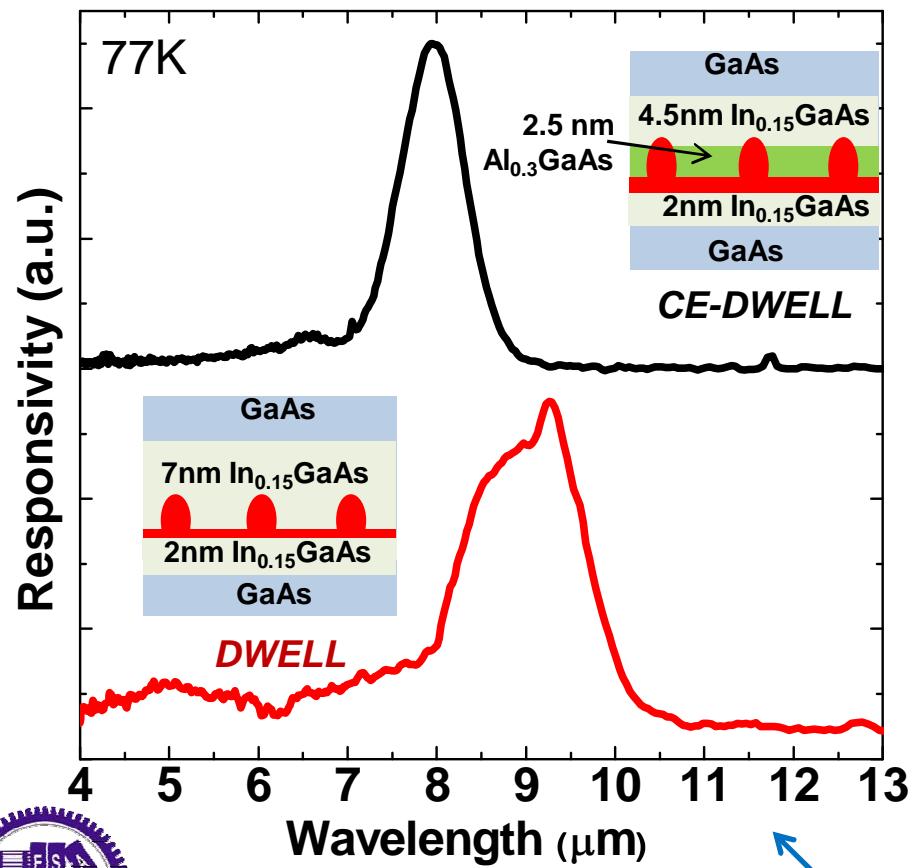


Cross-sectional TEM image of the CE- DWELL QDIPs

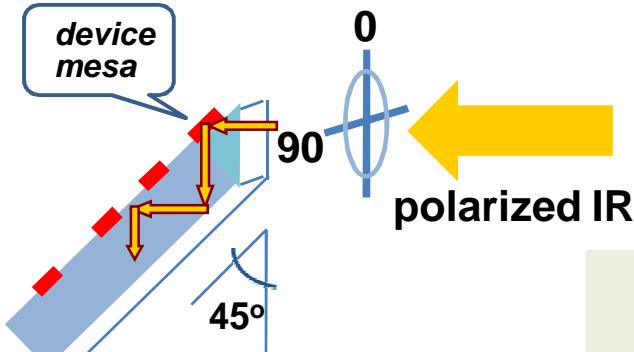


Compare CE-DWELL & DWELL

The infrared response is due to the bound-to-bound transition in QDs

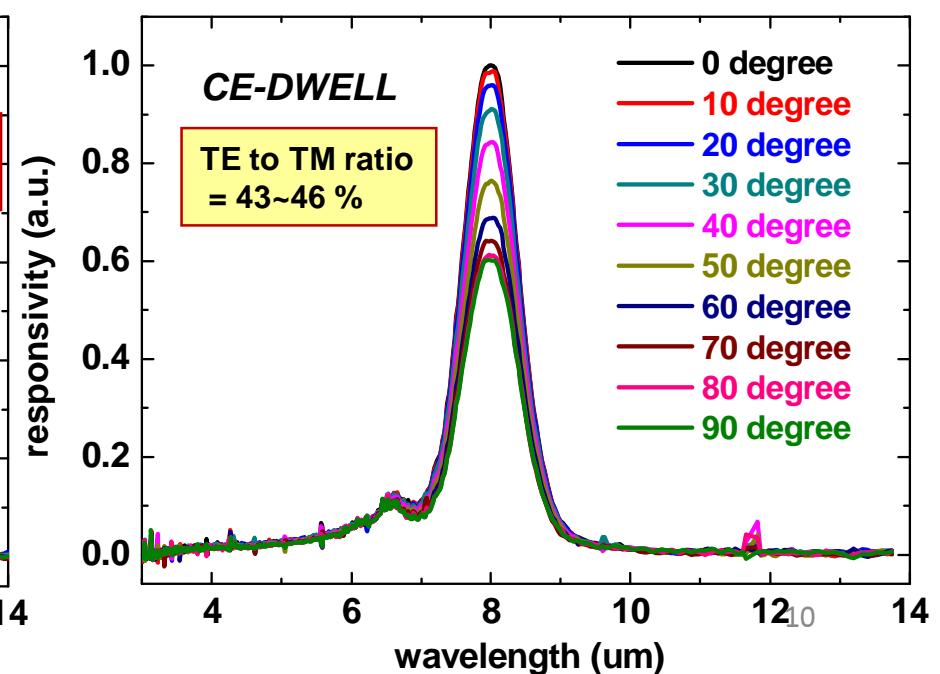
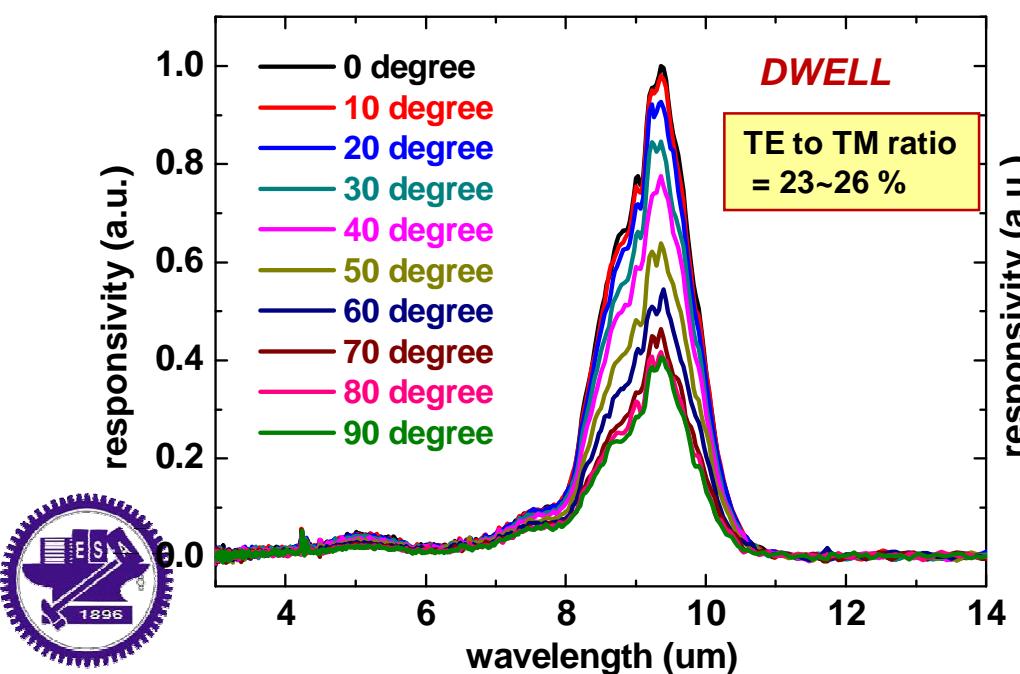
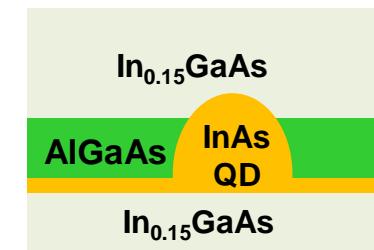
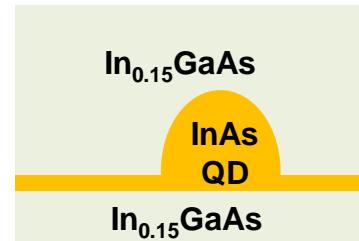


polarization dependent photo-response under the 45° edge-coupled configuration



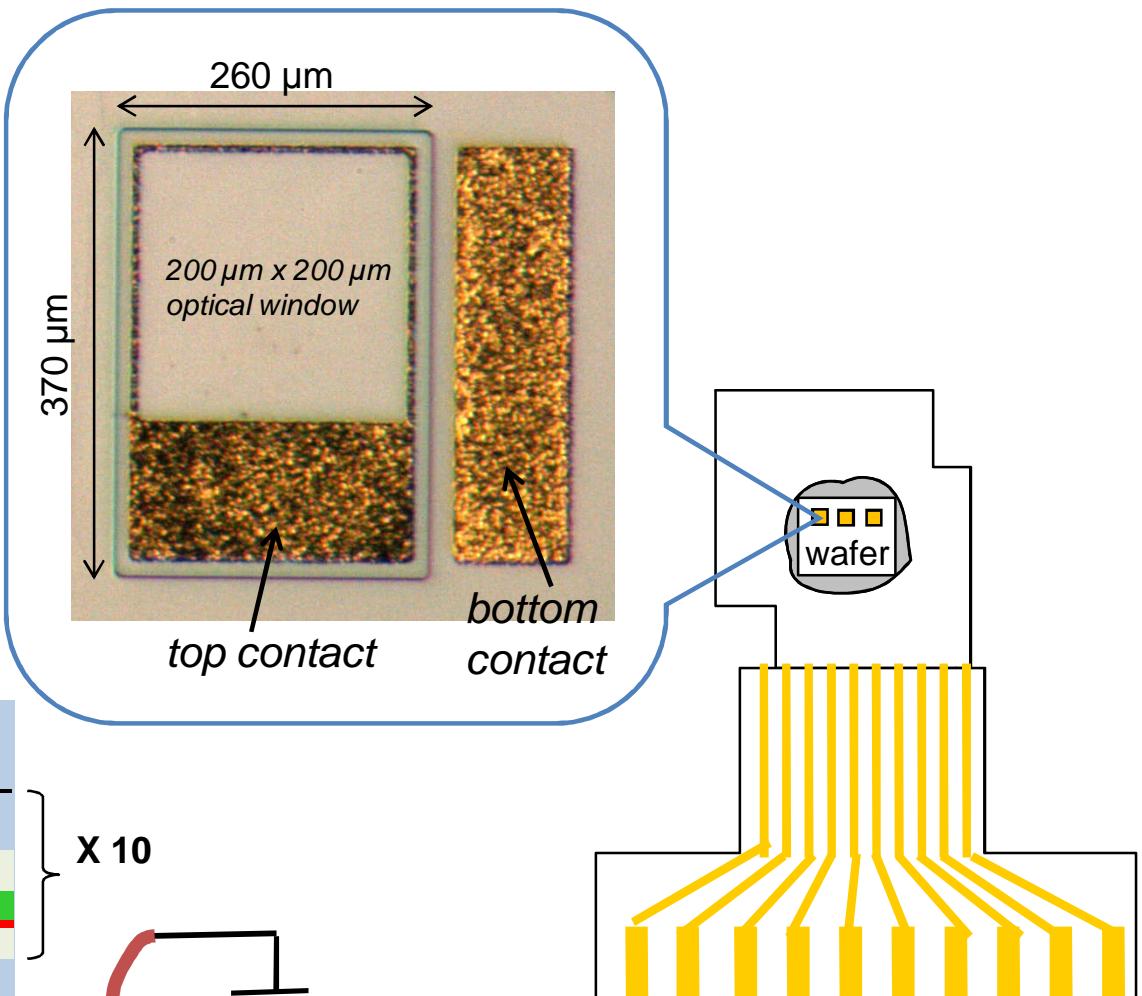
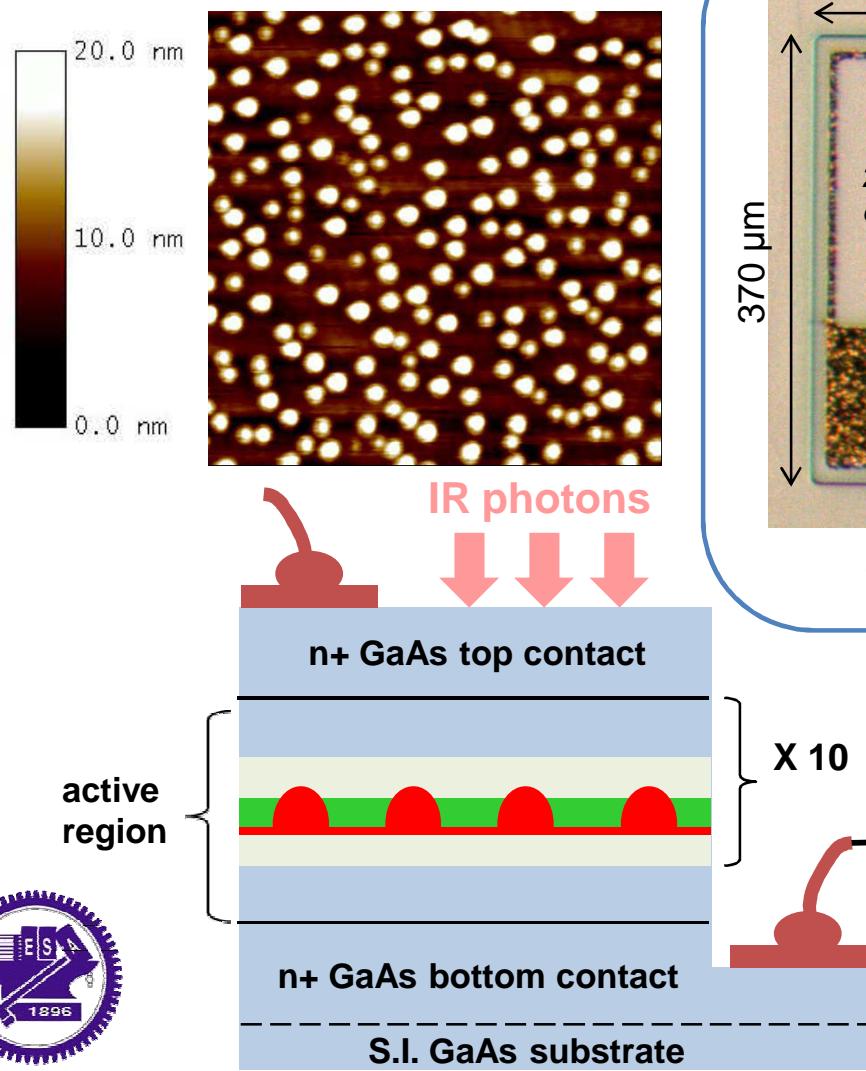
$0^\circ \rightarrow 50\% \text{TE} + 50\% \text{TM}$
 $90^\circ \rightarrow \text{TE}$

The thin AlGaAs layer effectively enhances the TE absorption

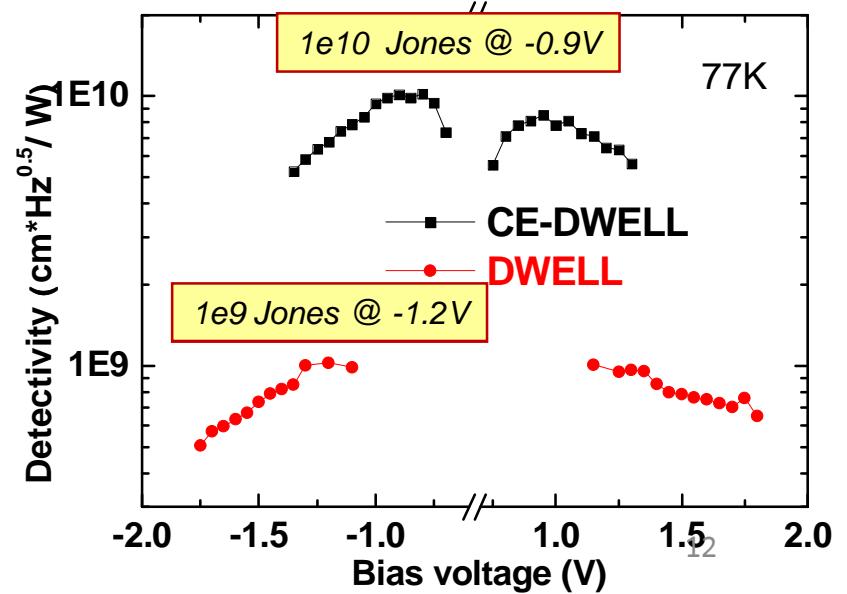
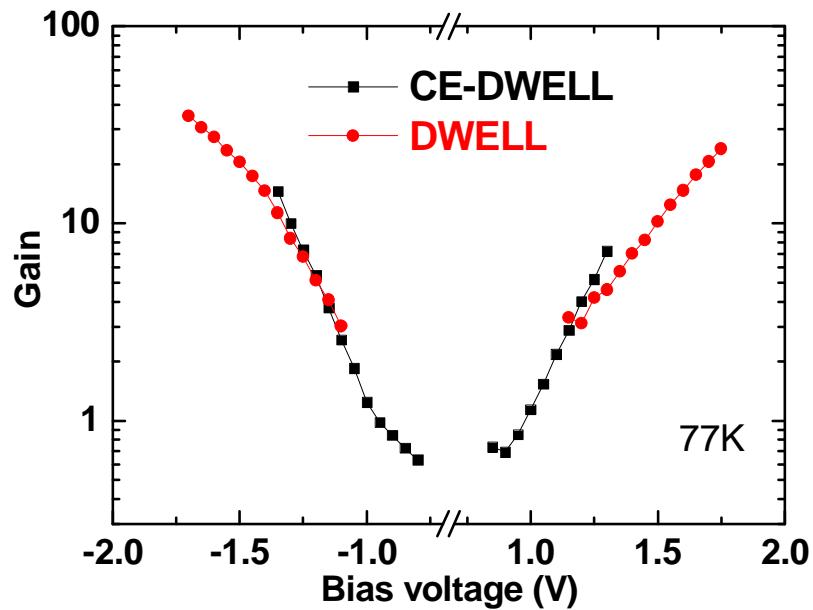
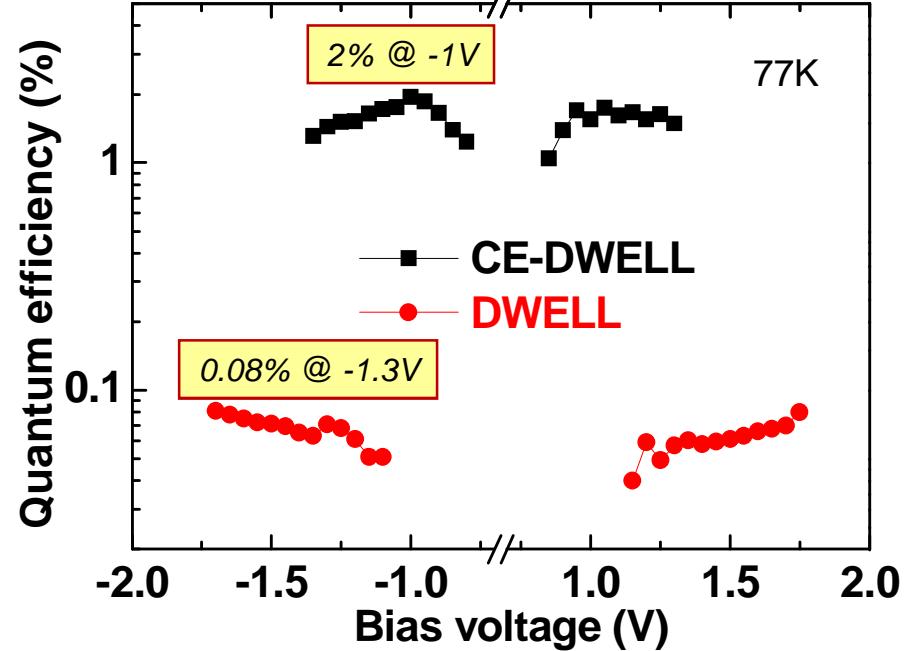
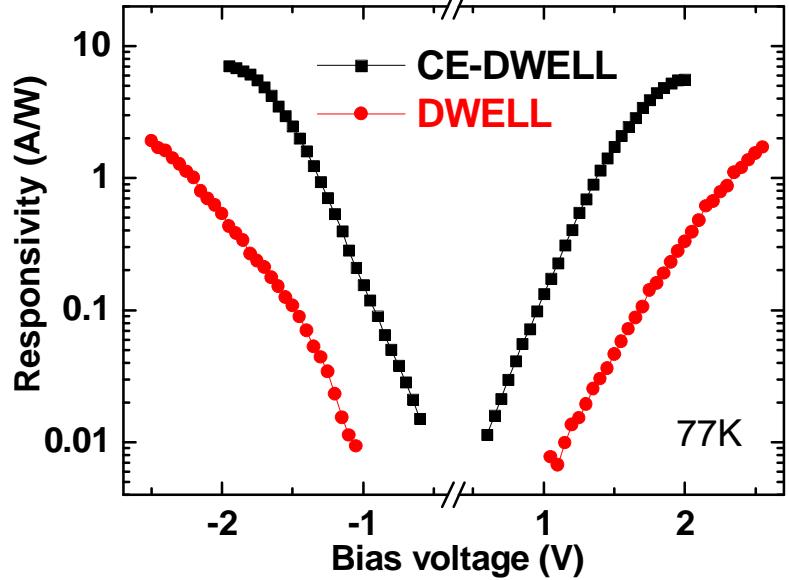


Device characterization under the normal incidence configuration

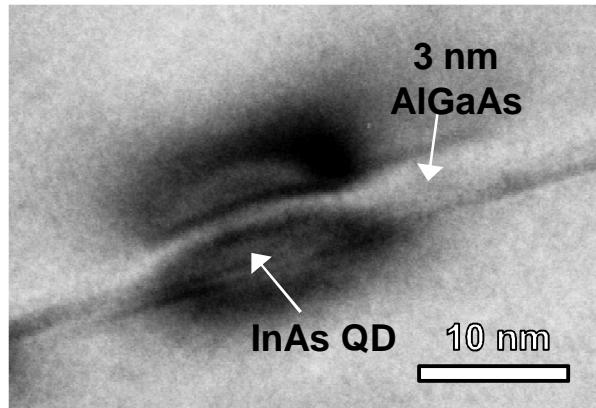
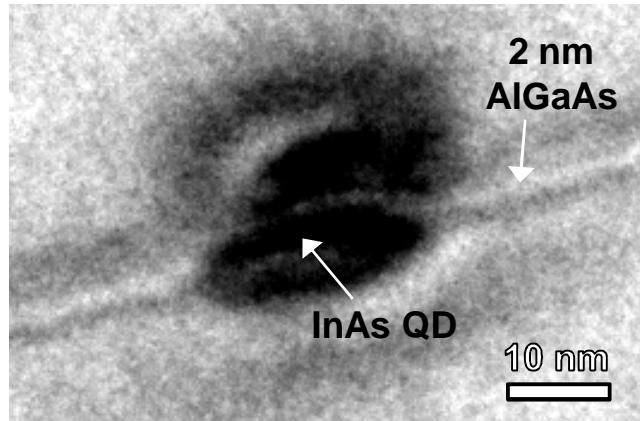
QD density: $\sim 2.1 \text{e}10 \text{ cm}^{-2}$



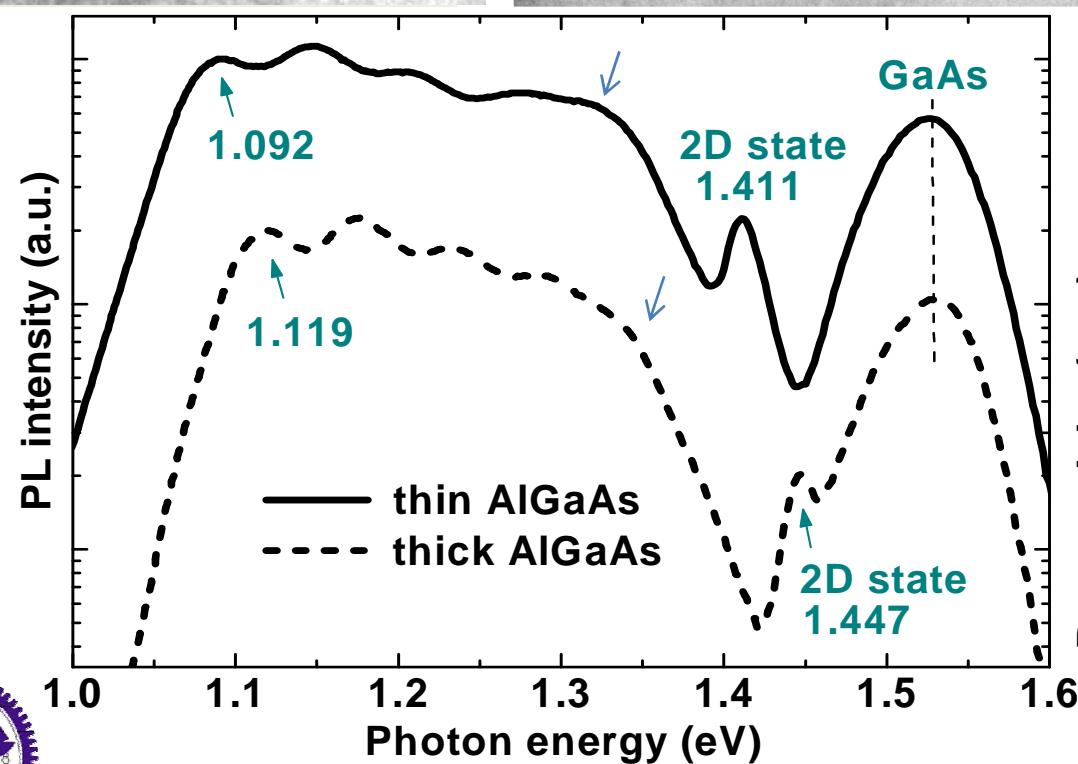
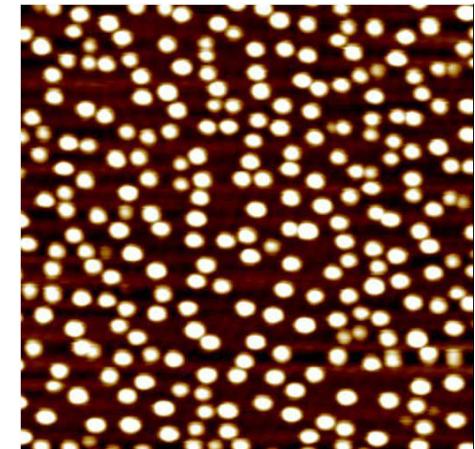
Compare CE-DWELL & DWELL: normal-incidence performance



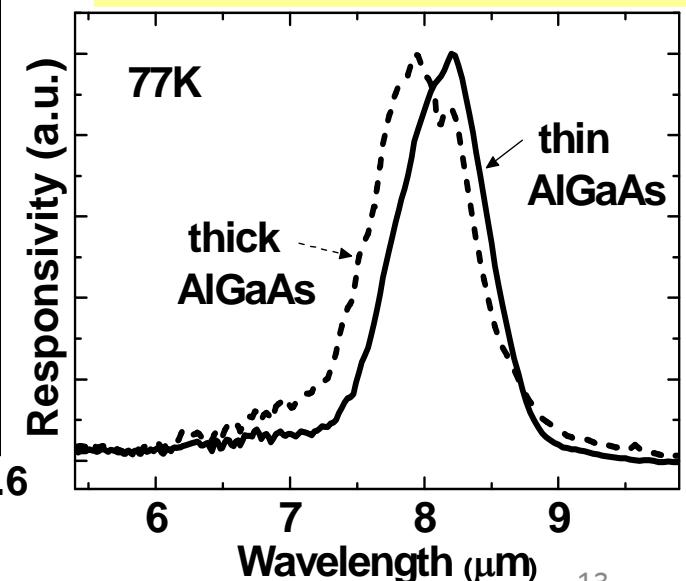
Effect of thickness on CE-layers



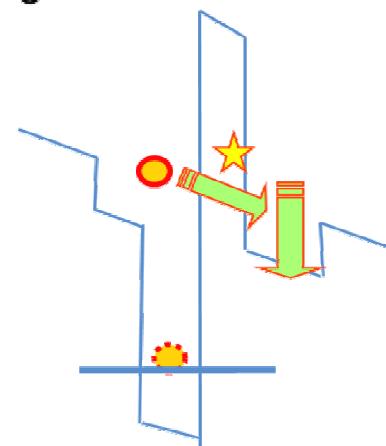
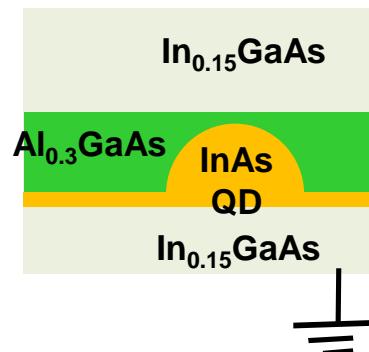
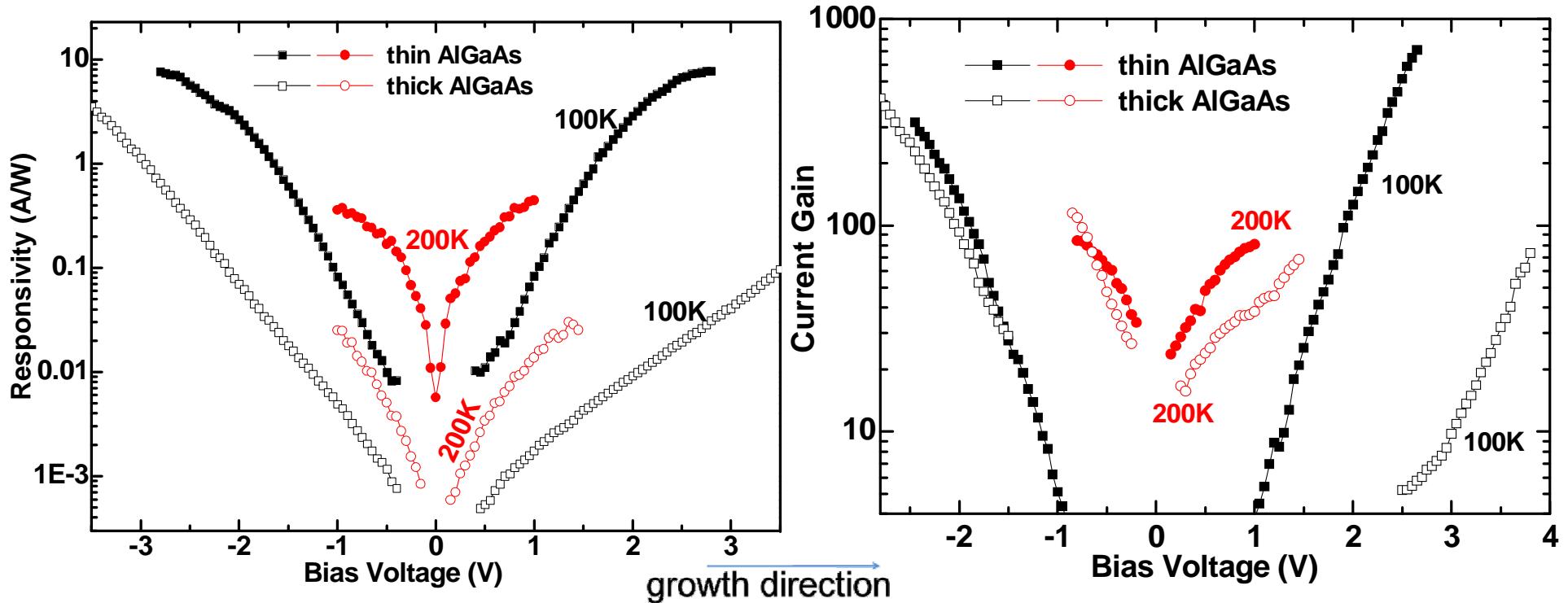
Thicker GaAs barrier(72nm)
Higher QD density



H=13~17 nm , D = 40~55 nm
Density: ~ $2.6 \times 10^{10} \text{ cm}^{-2}$



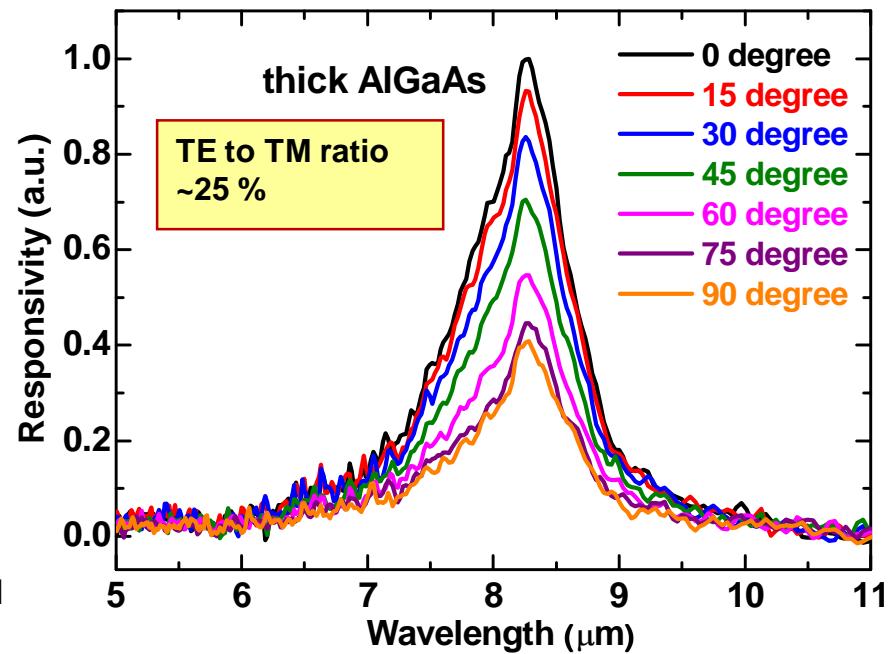
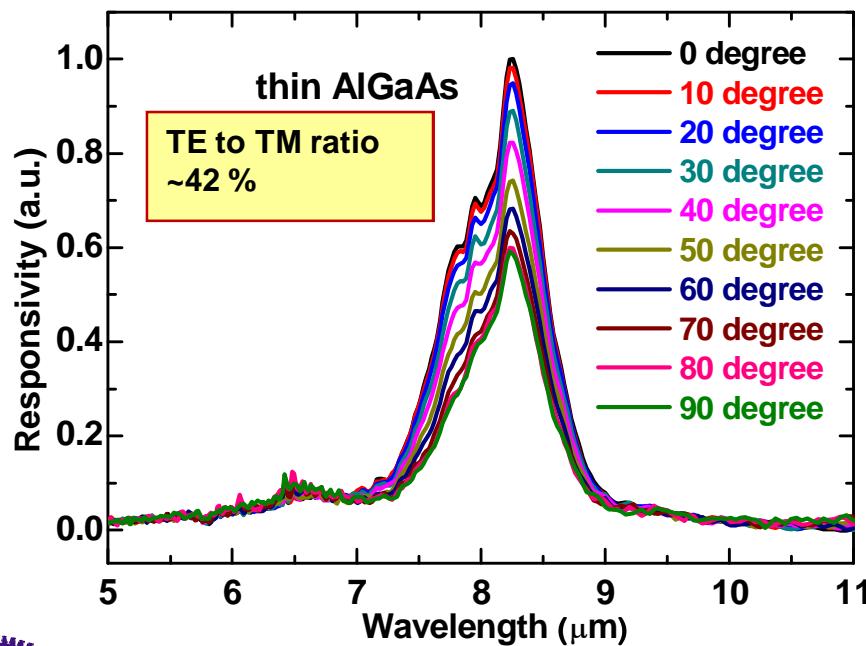
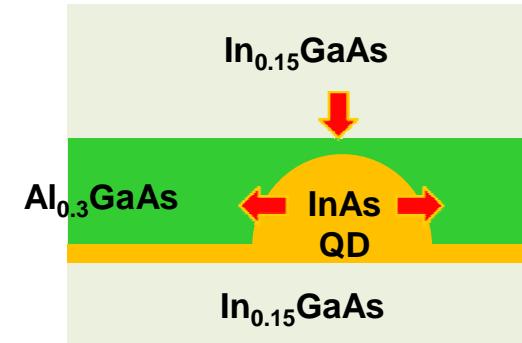
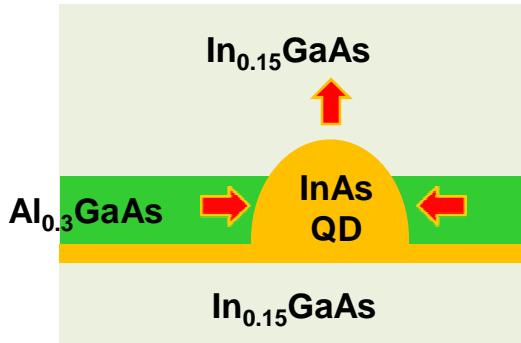
Thick AlGaAs device shows inferior responsivity & asymmetric gain behavior



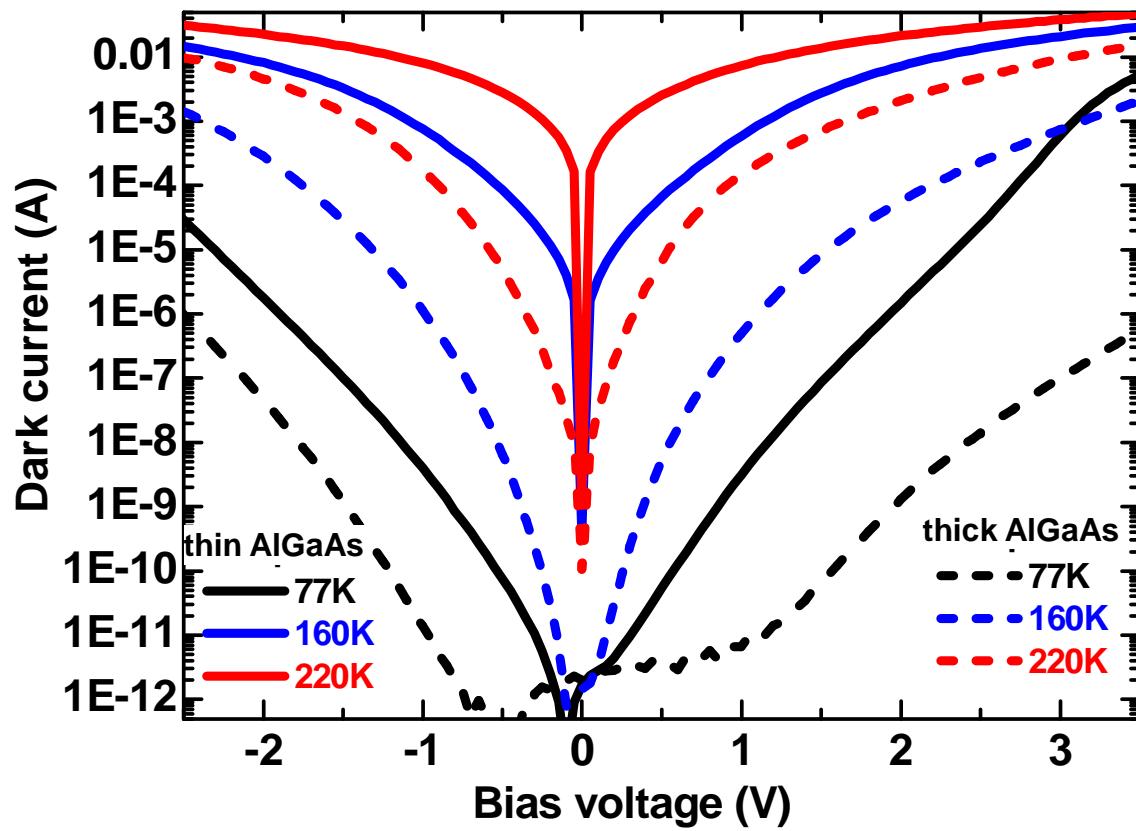
Positive bias:
Carrier retrapped into
the adjacent InGaAs QW



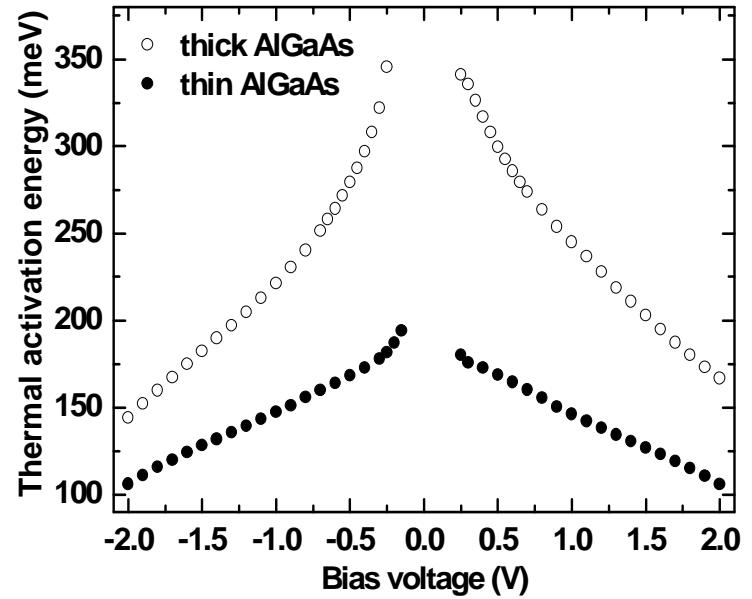
Thick AlGaAs device shows deteriorated TE/TM ratio and thereby lower normal incidence quantum efficiency



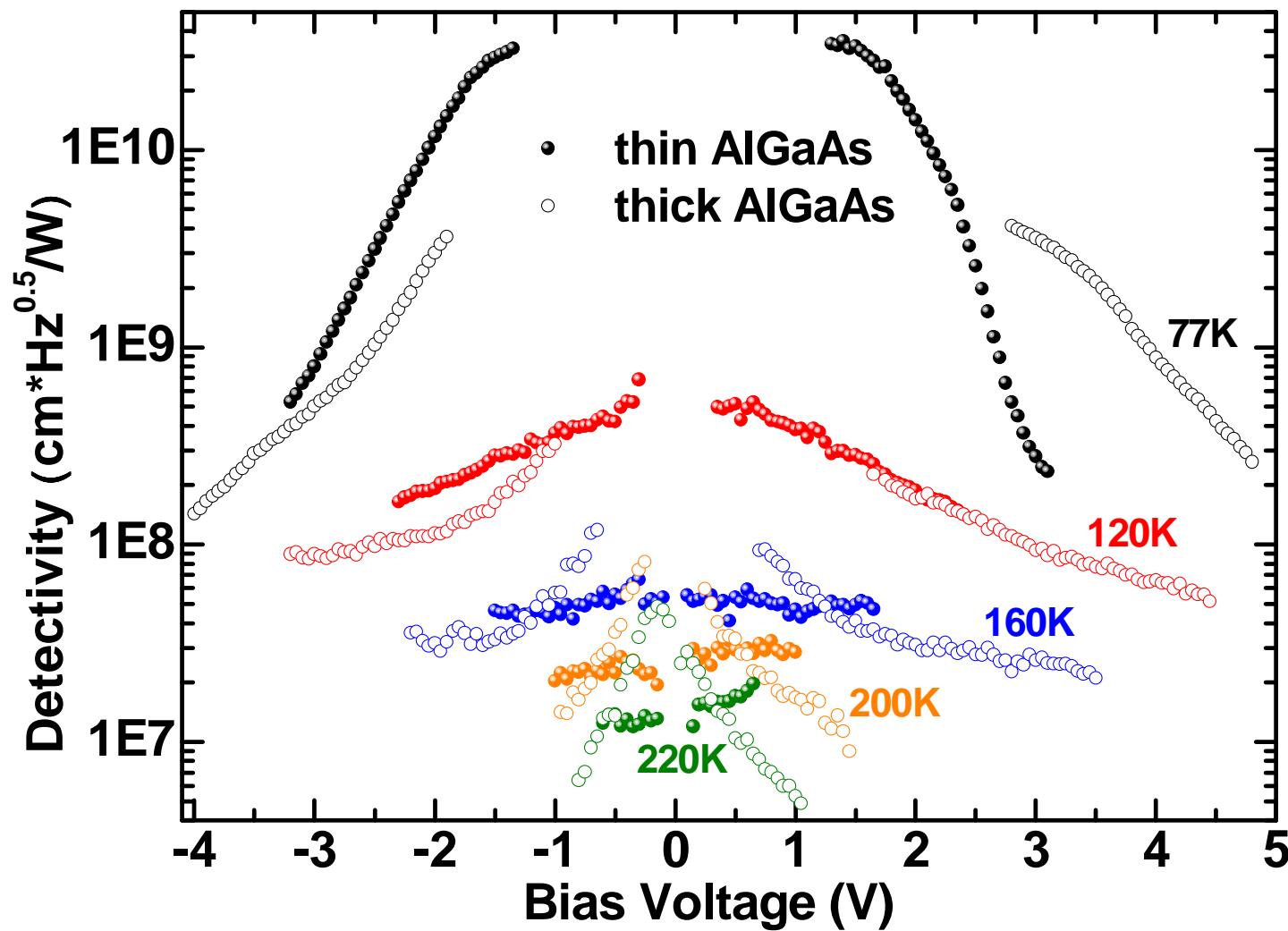
Although thick AlGaAs device has deteriorated responsivity, its dark current is also effectively suppressed, especially at small bias region at higher temperatures.



$$I_d \propto T * \exp\left(-\frac{E_a}{kT}\right)$$



So, the thick AlGaAs device starts to show better overall performance under high temperatures and low biases.

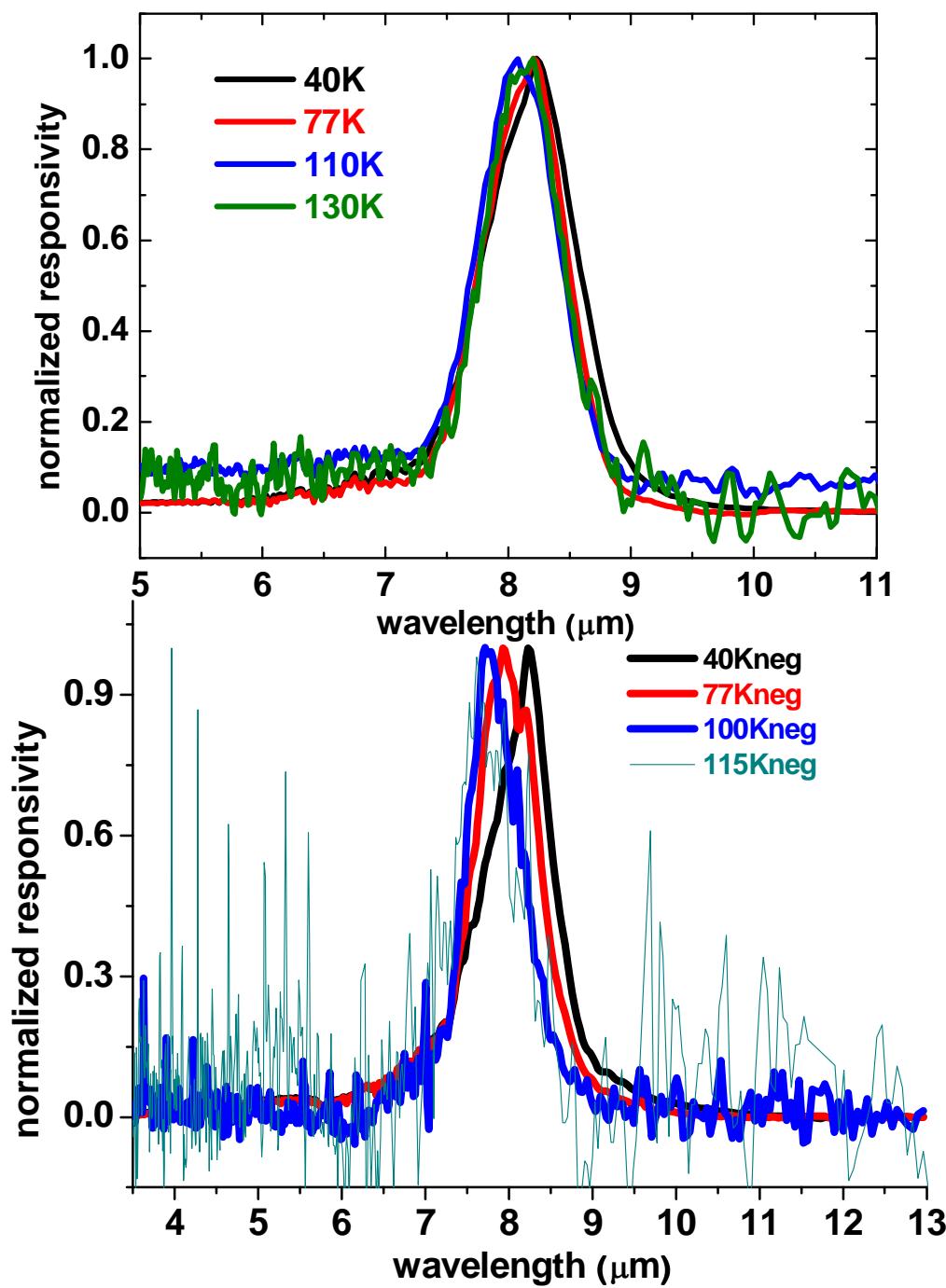


Conclusion:

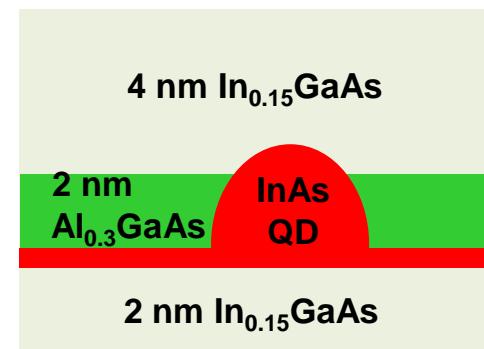
1. A novel **confinement-enhanced DWELL** structure was proposed for high performance LWIR QDIPs. Devices with the $8.2 \mu\text{m}$ detection peak and the operation temperatures higher than 200K were reported.
2. A thin AlGaAs layer was introduced as the confinement enhancing layer to improve the inherently weak lateral confinement of self-assembled QDs. The normal incidence quantum efficiency was greatly enhanced.
3. The AlGaAs layers not only changed the absorption properties but also influenced the carrier transport for QDIPs. One can effectively manipulated the device characteristics by using different parameters of AlGaAs layers.
4. The device with better performance at lower temperatures does not necessarily have better performance at elevated temperatures. Better suppression of the dark current is the key to the high temperature operation QDIPs.

Thank a lot for your attention!





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